



State-of-the-Art Status for Deep-Space SmallSat Telecom

2018 Int'l Planetary Probe Workshop

Short Course on Small Satellites

Boulder, Colorado; USA

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Outline

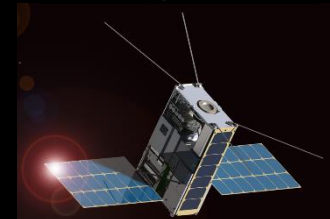
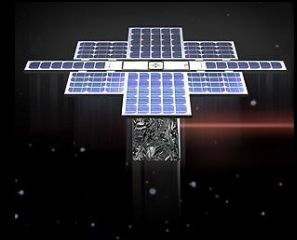
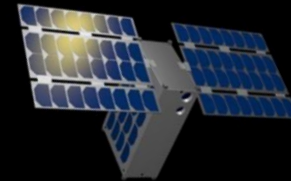
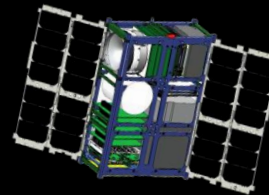
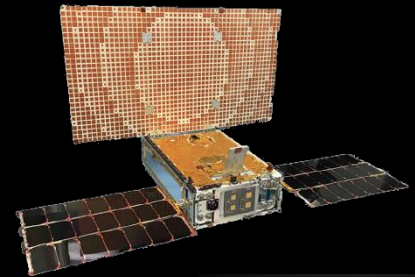
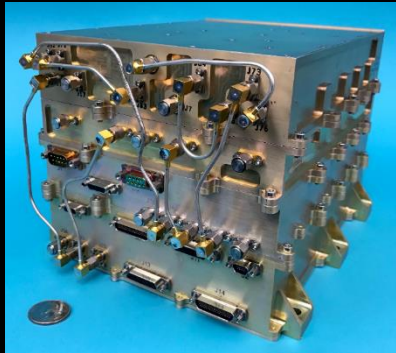
- Presenter Biography
- Deep-Space Telecom Challenges
- NASA's Deep-Space Network
- Telecom Subsystem Components
 - Spacecraft Deployable Antennas
 - Software Defined Radios
 - Power Amplifiers
- Current State-of-the-Art Development
- Future Topics
- Summary

Presenter Biography



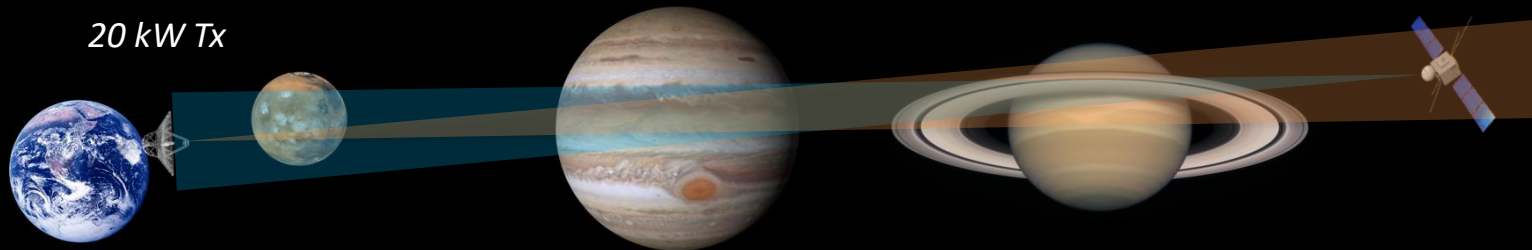
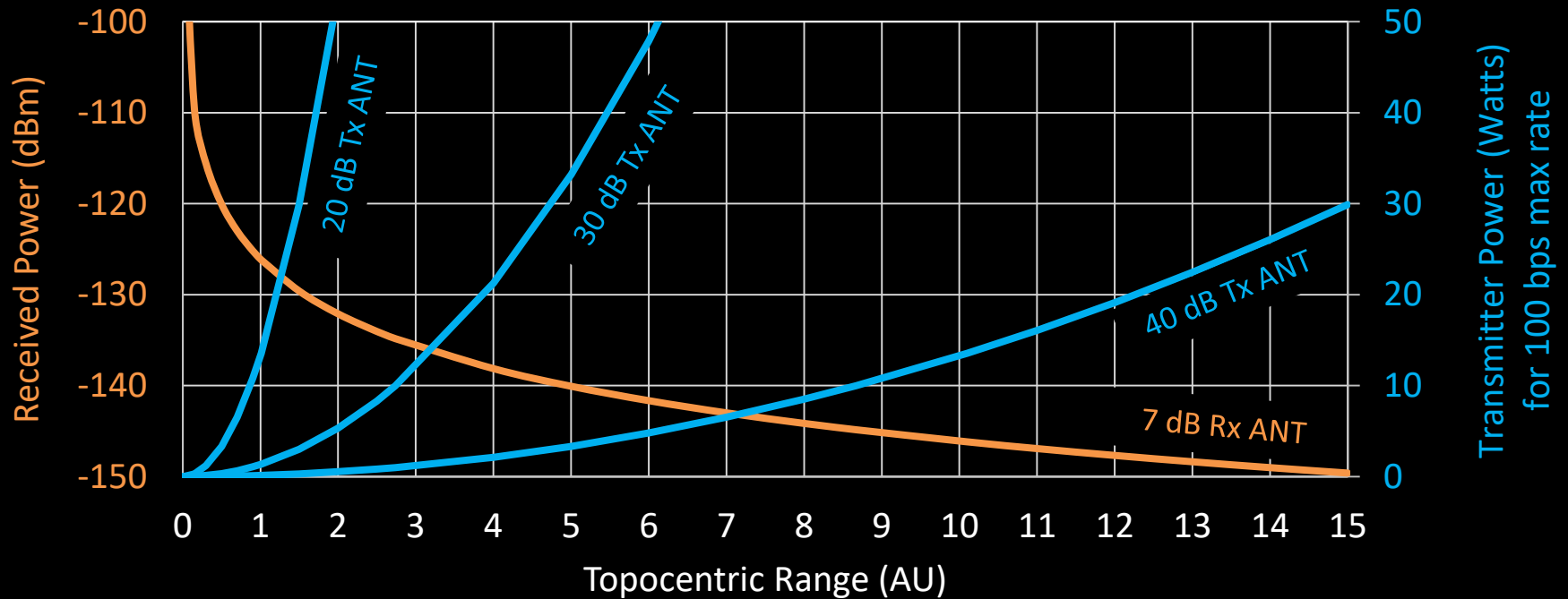
M. Michael Kobayashi (*B.S., M.S. in Electrical Engineering*)

- 10+ years experience at JPL
- Various flight hardware deliveries to
 - Mars Science Laboratory (aka Curiosity Rover)
 - Soil Moisture Active Passive (SMAP) Mission
 - Mars Cube One (first deep-space CubeSat)
 - NASA/ISRO Synthetic Aperture Radar (NISAR)

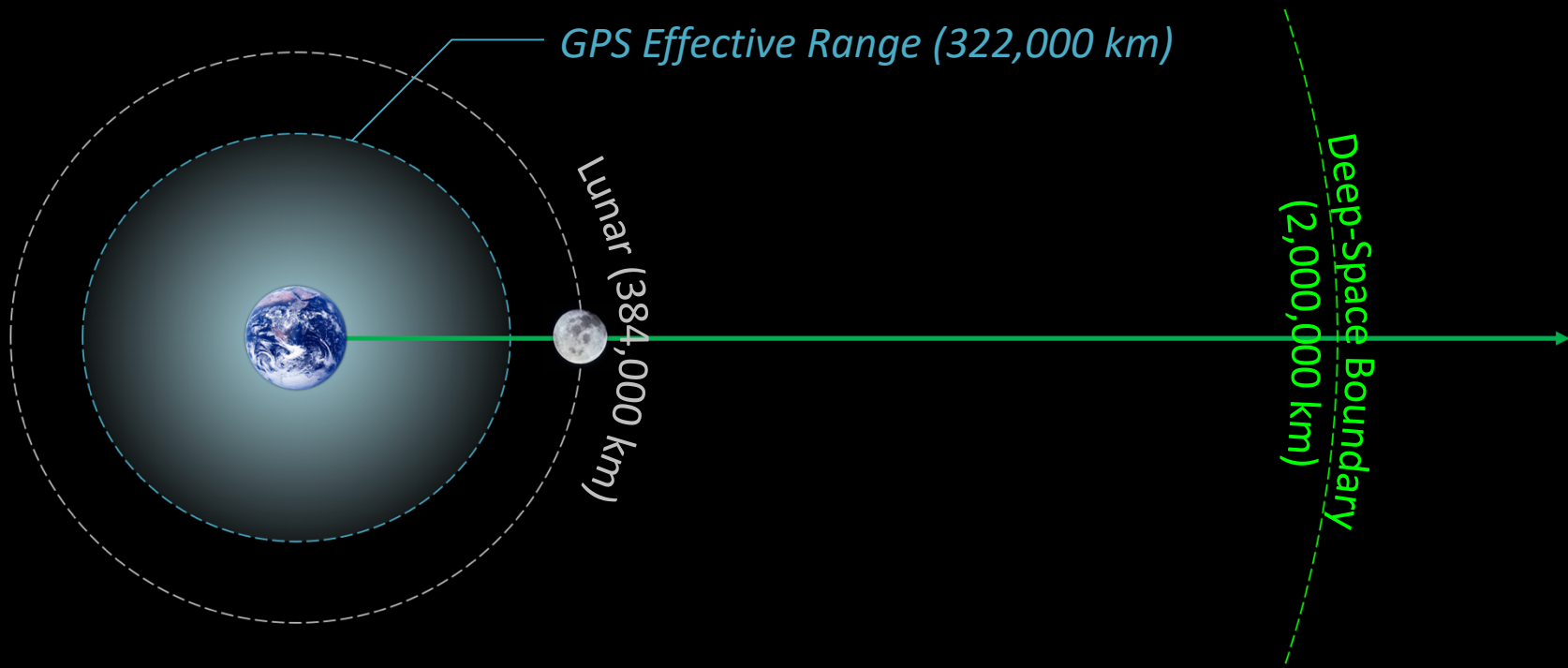


Challenge #1 – Long Distances

DSN 34-m Aperture at X-band



Challenge #2 – Time and Navigation



Spacecraft distance and velocity is determined by **radiometric techniques** from the ground

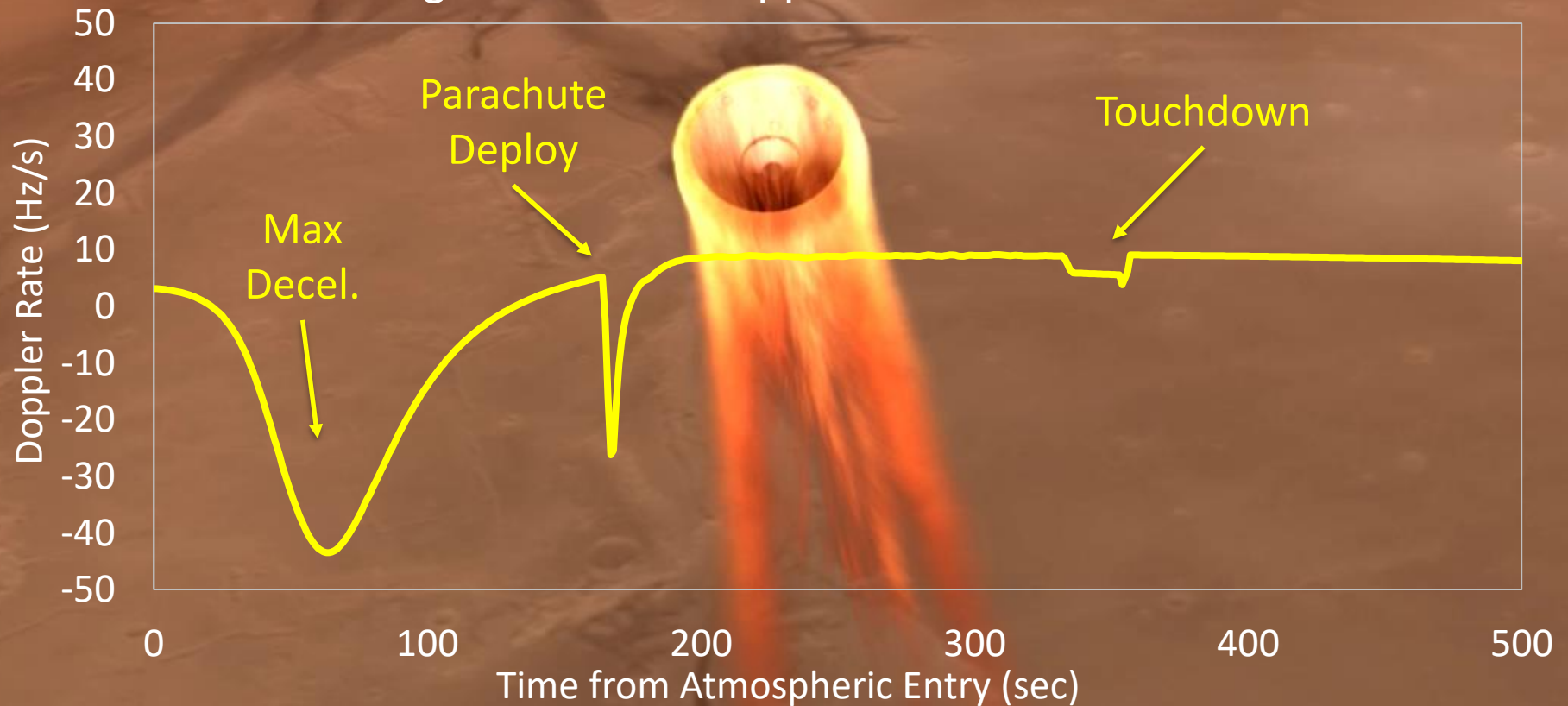
- Doppler tracking
- Ranging (Sequential or Pseudo-noise)
- Very Long Baseline Interferometry (VLBI)

A highly **stable clock** is necessary for the accuracy and precision for orbit determination (analogous to 18th century marine chronometers for longitudinal determination)

Challenge #3 – Spacecraft Dynamics



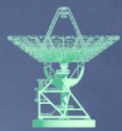
InSight Mars EDL Doppler Profile to MarCO



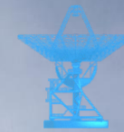
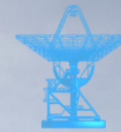
NASA's Deep Space Network



MADRID



GOLDSTONE



CANBERRA

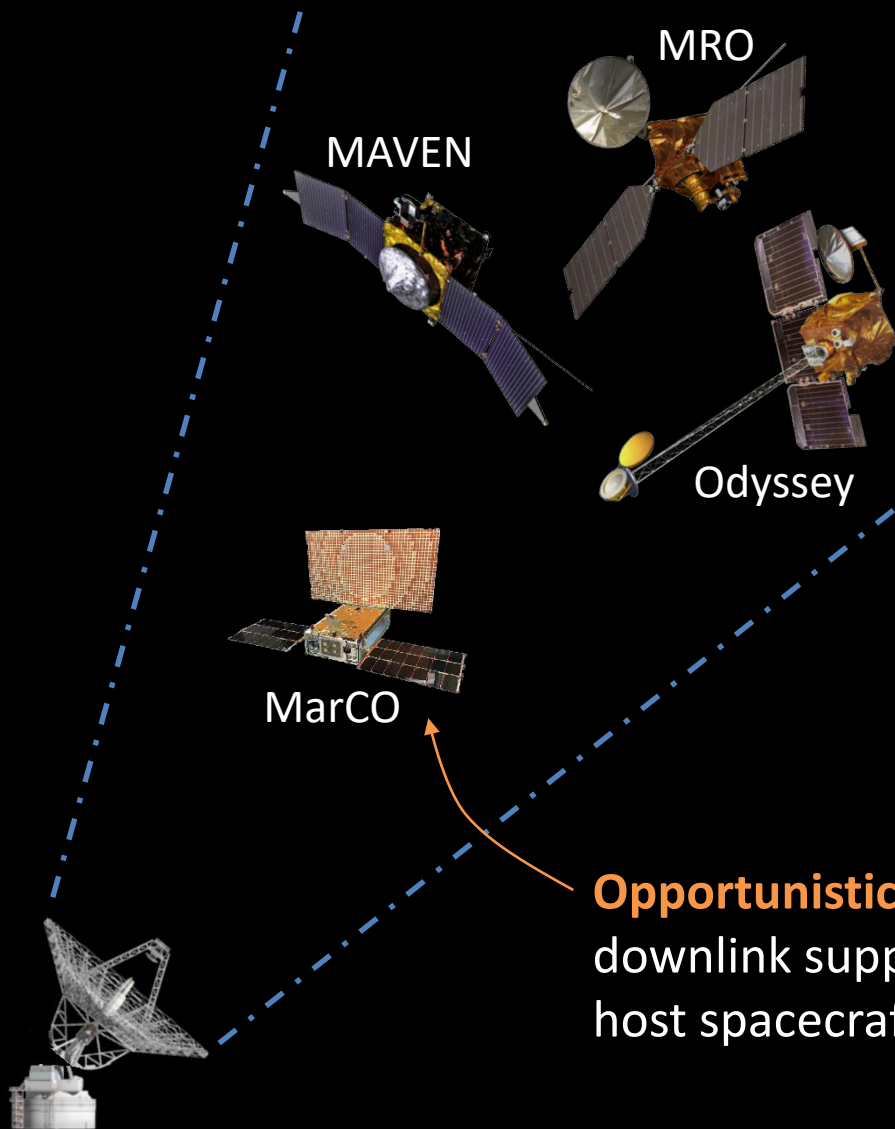


In commission
(2018)

Plans to be added as part of the DSN
Aperture Enhancement Project by 2025



Multiple Spacecraft Per Aperture (MSPA)



MSPA allows communication up to four spacecraft in an aperture beam

- Simultaneous downlink
- Sequential uplink commanding

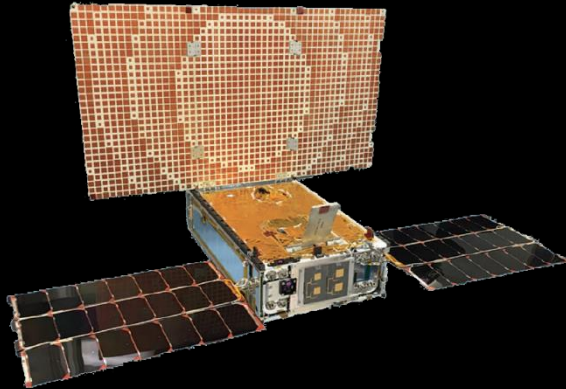
Example in-beam applications:

- Mars Network
- Sun-Earth Lagrange Points
- SmallSat Constellations

Opportunistic MSPA (OMSPA) provides open-loop downlink support for SmallSats if they are in-beam to host spacecraft antenna beam

Spacecraft Deployable Antennas

Deployable Reflectarray

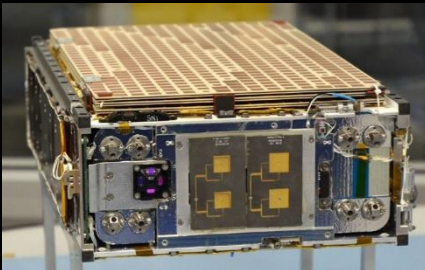


X-band

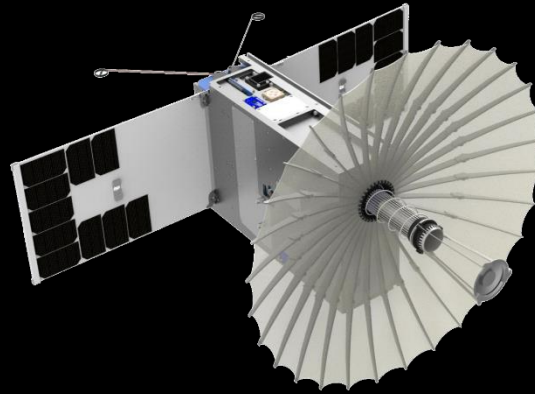
Gain: 29.2 dBi

Dimensions: 59.7 x 33.5 cm

Stowed: 20 x 33.5 x 1.25 cm



Deployable Parabolic



Ka-band

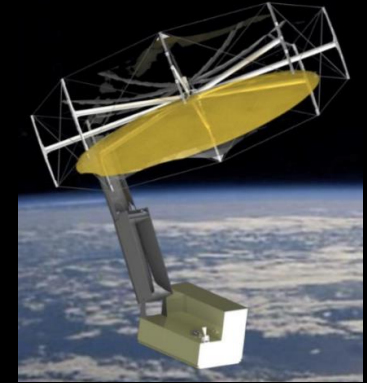
Gain: 42.6 dBi

Diameter: 0.5 m

Stowed: 10 x 10 x 15 cm



Deployable Reflector



Ka-band

Gain: 49.2 dBi

Diameter: 1.0 m

Stowed: 2.5 U

- [1] R. E. Hodges, et.al, "A Deployable High-Gain Antenna Bound for Mars: Developing a new folded-panel reflectarray for the first CubeSat mission to Mars.," in IEEE-APS, vol. 59, no. 2, pp. 39-49, April 2017.
- [2] N. Chahat, et.al., "Deep Space Network Telecommunication CubeSat Deployable Ka-band Mesh Reflector Antenna", IEEE-APS Trans. June 2016.
- [3] Y. Rahmat-Samii, et.al., "Ka-band Highly Constrained Deployable Antenna For Raincube: Engineering Development and Pattern Measurements", IEEE-APS Symp. 2018.

JPL Flight SDR Developments

- Leading the pathway to “**smart radios**”
 - Reconfigurable to adapt to mission-specific needs
 - Platform for rapid technology infusion
 - Delay/Disruption Tolerant Networking
 - Pseudo-noise (PN) Regenerative Ranging
 - Advanced higher-order modulation schemes
 - State-of-the-art Forward Error Correction algorithms



MRO Electra
UHF Relay Radio



MSL Electra-Lite
UHF Relay Radio



CoNNeCT
S-band Radio



TGO Electra
UHF Relay Radio



M2020 Electra-Lite
UHF Relay Radio

JPL Flight Software-Defined Radio Developments

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

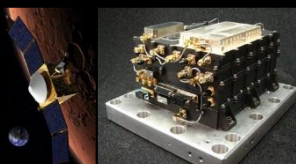
M3
Instrument



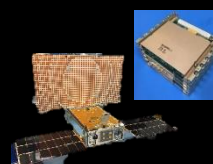
MSL Landing
Radar Digital
Assembly



MAVEN Electra
UHF Relay Radio



MarCO Iris Deep-
Space Transponder



M2020 Landing
Radar Digital
Assembly



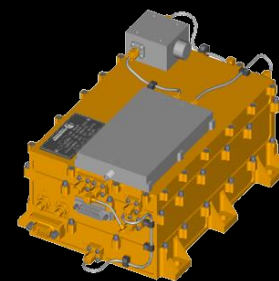
NISAR Ka-band
Modulator



JPL Deep-Space Transponders



Radio Specification	Units	Iris	UST-DS	UST-Lite*
Frequency Bands		X up, X down	S/X up, S/X down Simultaneous dual band	X/Ka up, X/Ka down Simultaneous dual band
Mass	kg	1.0	5.4	3.0
Volume	cc	600	7500	2700
Bus Input Voltage	Vdc	9 – 28	22 – 36	22 – 36
DC Power	W	16	45	30
Processors		Xilinx V6 + Leon-3FT	Xilinx V5 + SPARC V8	Xilinx V5 + Leon-3FT
Receiver Noise Figure	dB	3.5	2.1	2.1
Receiver Sensitivity	dBm	-151 @ 20 Hz LBW	-160 @ 20 Hz LBW	-160 @ 20 Hz LBW
Uplink Rate	sps	62.5 – 8k	7.8125 – 37.5M	7.8125 – 37.5M
Downlink Rate	sps	62.5 – 6.125M	10 – 300M	10 – 300M
Telemetry Encoding		Conv, RS, Turbo	Conv, RS, Turbo, LDPC	Conv, RS, Turbo, LDPC
Radiation Tolerance (TID)	krads	23	50	300
S/C Interface		1 MHz SPI	1553, SpaceWire, RS-422	1553, SpaceWire, RS-422



Deep-Space Transponder Comparisons

Iris^[1]



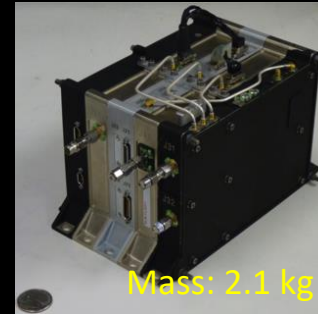
Mass: 1.0 kg

SDST^[2]



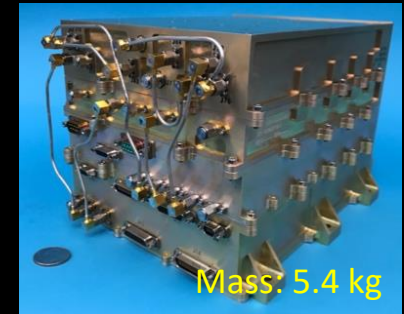
Mass: 3.3 kg

Frontier^[3]



Mass: 2.1 kg

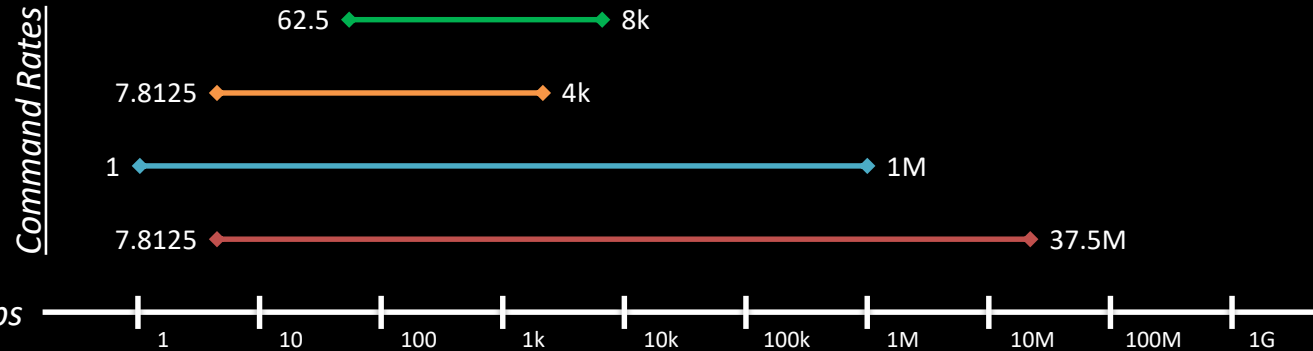
UST^[4]



Mass: 5.4 kg

Iris	-151 dBm
SDST	-158 dBm
Frontier	-160 dBm
UST	-160 dBm

Rx Thresh.



Frontier	9.7 W
Iris	16.0 W
SDST	17.9 W
UST	45.0 W

Power (excl. SSPA)



[1] M. Kobayashi, "Iris Deep-Space Transponder for SLS EM-1 CubeSat Missions", SmallSat Conf., Aug 2017.

[2] General Dynamics, "Small Deep Space Transponder" available online <http://gdmissionsystems.com>

[3] M. B. O'Neill, et.al., "Advances in Deep Space Radios", IEEE IMS, June 2017.

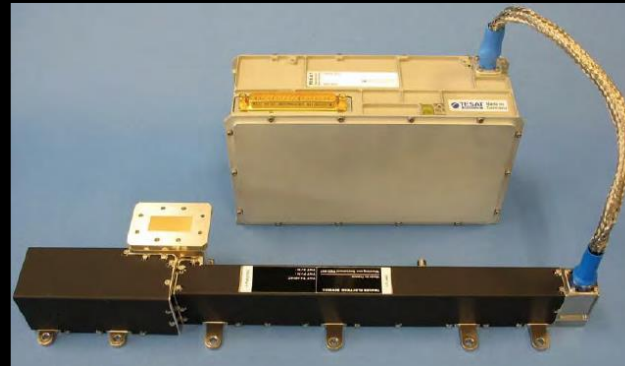
[4] M. Pugh, et.al., "The Universal Space Transponder: A Next Generation Software Defined Radio", IEEE AeroConf, Mar 2017.

X-band Power Amplifiers

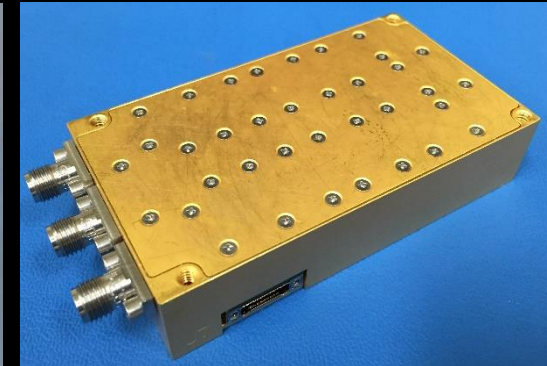
Vendor	Type	Heritage	RF out / DC in	PAE	Mass	Volume
JPL/SDL	SSPA	MarCO, EM-1	4 / 17 W	23.5 %	150 g	66 cc
GD	SSPA	MER, MSL	17 / 59W	28.8 %	1320 g	1096 cc
TESAT	TWTA	JUNO	25 / 56 W	44.6 %	4800 g	N/A
TESAT	TWTA	MRO	102 / 172 W	59.3 %	4900 g	N/A



General Dynamics SSPA



TESAT TWTA and EPC



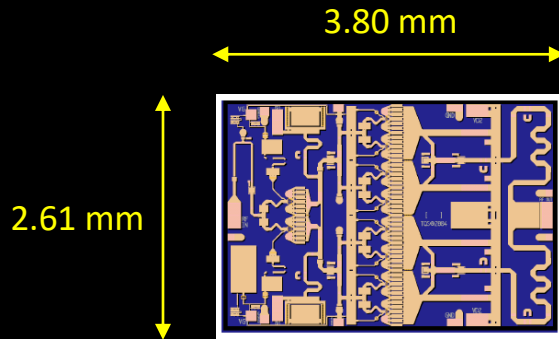
Space Dynamics Lab SSPA

To increase downlink data rates of SmallSats,
lower mass/volume SSPA with **higher RF output power** is desired

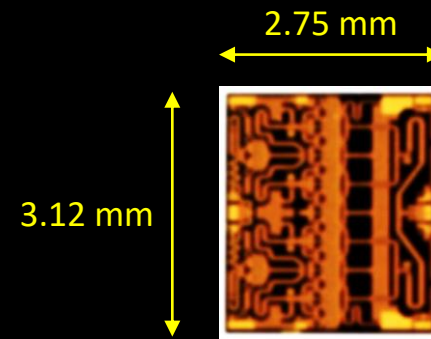
Current State-of-the-Art Development

Push for new Gallium Nitride (GaN) technology amplifiers

- High power density (smaller package, higher power)
- High junction temperature tolerance (more reliable)
- High radiation tolerance (reduce shielding and mass)



TriQuint TGA2701
5.0 W output
0.5 W/mm²



Qorvo QPA1011D
31.6 W output
3.7 W/mm²

15% size reduction, but 6x power
~ 7.5x power density

Current State-of-the-Art Development

S-band is effectively closed due to limited bandwidth and terrestrial interference

X-band is the current workhorse for deep space communication, but getting crowded

Ka-band is largely unused

- ~10x bandwidth capacity
- ~16x antenna gain efficiency
- ~4x radiometric precision

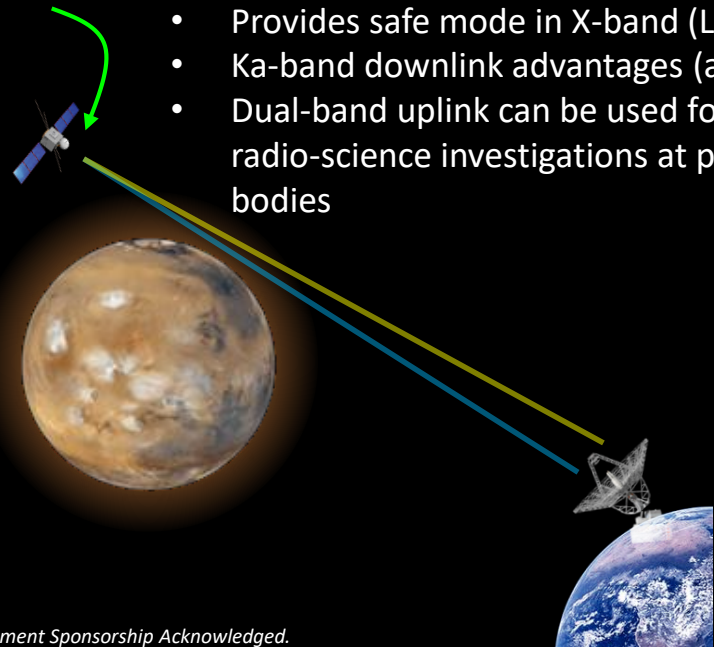


Ka-band Parabolic Deployable Antenna (stowed config)

3D-printed diplexer mounted to KaPDA

X/Ka/Ka Dual-band Radio

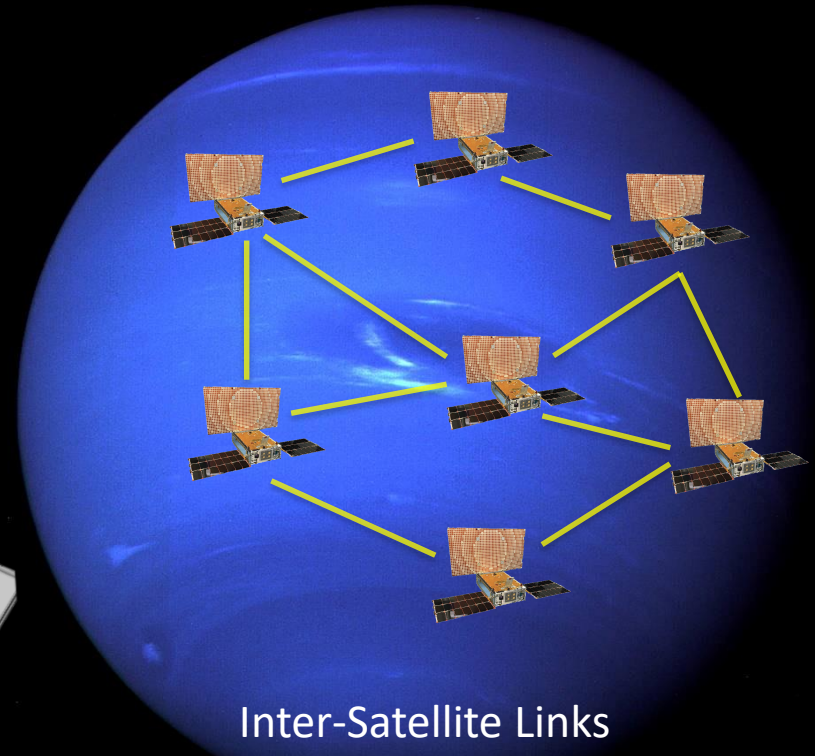
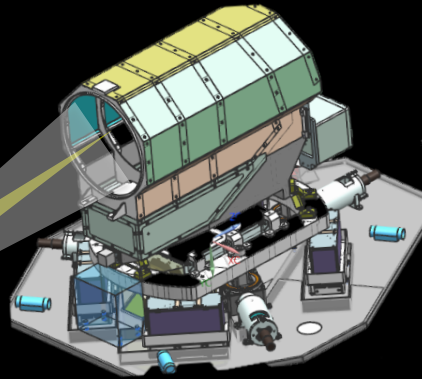
- Provides safe mode in X-band (LGA)
- Ka-band downlink advantages (above)
- Dual-band uplink can be used for radio-science investigations at planet bodies



Additive manufacturing methods for miniaturized Ka-band passive elements

Some Future Topics to Address

Overloading and mission scheduling
How to talk to 100's of SmallSats??



Inter-Satellite Links
Constellation/Mesh Networking

Proposed Deep-Space Optical Comm
Ground Terminal Architecture

Summary

- Unique challenges of deep-space telecom
- The Deep Space Network continues to provide the ground infrastructure for telecom and navigation
- Software defined radios are advancing smart radio capabilities to enable rapid technology infusion
- Ka-band systems are not only advantageous, but will be a necessity for future SmallSats



Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov